

# Evaluation of the effectiveness of traffic control algorithms based on a simulation model in the AnyLogic

Ya I Shamlitskiy<sup>1</sup>, S N Mironenko<sup>1</sup>, N V Kovbasa<sup>1</sup>, N V Bezrukova<sup>1</sup>,  
V S Tynchenko<sup>1,2</sup> and V V Kukartsev<sup>1,2</sup>

<sup>1</sup>Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Avenue, Krasnoyarsk, 660037, Russia

<sup>2</sup>Siberian Federal University, 79, Svobodny Avenue, Krasnoyarsk, 660041, Russia

E-mail: 2538357@mail.ru

**Abstract.** The increase in the number of vehicles every year covers an growing number of countries, as a result of which the vehicle fleet of large cities and megalopolises is constantly increasing, as well as the number of people involved in traffic. The growth in traffic leads to the increase in traffic intensity, which in the conditions of cities with historically developed buildings leads to a transport problem. It is particularly acute in the nodal points of the road network. The problems are caused by the increase in transport delays, queuing and congestion, which in turn causes the decrease in the speed of communication, unnecessary consumption of fuel and increased wear of components and assemblies of vehicles. Effective traffic management involves the use of both network and local adaptive control algorithms. City-wide automated system should be based on the principles of maximum management efficiency and reliability of the system.

## 1. Introduction

Traffic management in conditions of maximum saturation of roads with transport and pedestrian traffic requires more and more advanced traffic control methods. Lately, the use of the Adaptive Traffic Control System (ATCS), which are a set of technical tools that implements certain traffic control algorithms, is becoming increasingly important.

The main purpose of the implementation of ATCS is to reduce the total delays of vehicles at intersections in the zone of the system – at a crossroads, in a district or city. General requirements for ATCS are defined by State Standard 24.501 – 82 “Adaptive Traffic Control Systems. General requirements”.

One of the main parameters characterizing the traffic on the road network is the traffic density of vehicles. At the same time, the traffic density at the regulated intersection can be divided into two components:

- arrival flow rate at the intersection approach;
- departure (saturation) flow rate from queue during effective green.

The Level of Service (LOS) is borrowed from queuing theory and is used to evaluate the vehicles movement conditions. The main characteristics of a queuing system (the queue length at a certain point in time, the length of the period during which the nth request is waiting for service, the average length of stay of a request in the system, etc.) often require complex calculations. Therefore, the idea arose to use such a simple characteristic as clearing ratio in order to evaluate traffic flow conditions

$$k = NP, \quad (1)$$

where  $N$  is arrival intensity;  $P$  is service rate.

The accuracy of the method for calculating the average delay is of fundamental importance, since, based on the average delay, the queue length is estimated and the total delay is determined. Webster's formula is recommended in our country for practical calculations of the average delay per vehicle

$$d = \frac{C(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0.65 \left( \frac{C}{q^2} \right)^{1/3} x^{(2+5\lambda)}, \quad (2)$$

where  $C$  is cycle length (sec);  $\lambda$  is relatively effective green time;  $x$  is a degree of saturation;  $q$  is arrival rate (veh/sec).

Included in the formula (2)  $\lambda$ ,  $x$  and  $q$  are defined as

$$\lambda = g/C; \quad (3)$$

$$x = \frac{Q}{\lambda M} = \frac{gQ}{CM}; \quad (4)$$

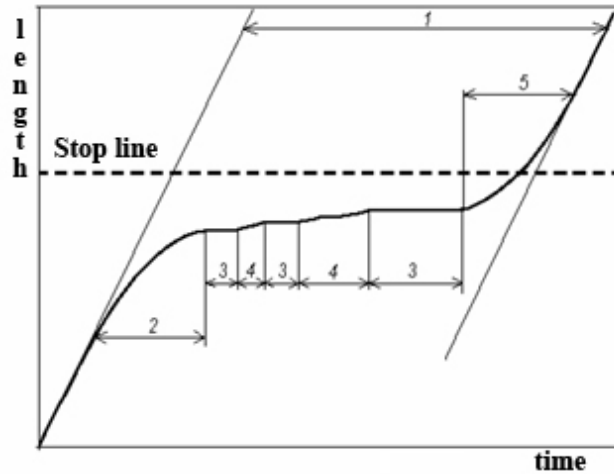
$$q = Q/3600. \quad (5)$$

here  $g$  is effective green time (sec);  $Q$  is arrival rate (veh/h);  $M$  is saturation flow (veh/h).

Total delay refers to the delay of all vehicles for a certain period within the considered road network or its part. The total delay was used as a criterion for the quality of motion control by Miller [1]. This criterion is closely correlated with the queue length, the average delay and traffic intensity. The total delay is more suitable for economic assessment on the scale of a whole road network or a district than the average delay, which mainly characterizes the quality of service of an individual vehicle [1].

The maximum delay is considered as the biggest delay of one of the vehicles for the period under consideration. It closely correlates with the value of the traffic flow entering the intersection and the queue length at the intersection approach. The duration of the maximum delay can be used as an indicator of the intersection supersaturation degree, but this method of determining is much more complicated than other types of delays. Therefore, it is considered for descriptive purposes.

In the Highway Capacity Manual 2000 [2], the so-called control delay is used as an indicator of the level of service at regulated and unregulated intersections. The term Control Delay has the following definition: a delay resulting from a deceleration or a stop and is measured as the difference between the time spent moving without regulation. An explanation of this term is given by the distance-time diagram (Figure 1). In connection with the use of the new criterion of the service levels boundaries at regulated intersections, we obtained the values (Table 1). Hereinafter, this indicator will be called the delay caused by the organization of the movement, and is denoted by ACD (Average Control Delay).



**Figure 1.** Losses in time included in Average Control Delay.

On Figure 1 ACD consists of few different delays: 2 – Deceleration delay; 3 – Stopped delays; 4 – Queue move-up-delays; 5 – Acceleration delay.

**Table 1.** Gradations of service levels for regulated intersections (HCM 2000) [3]

Service levels	Traffic conditions	Average Control Delay, sec
A	Delay is missing or small	$\leq 10$
B	Insignificant regulation cycle time, good coordination	10.1 – 20
C	Increased regulation cycle time, sufficiently good	20.1 – 35
D	Significant regulation cycle time, sufficiently good	35.1 – 55
E	Significant regulation cycle time, poor coordination	55.1 – 80
F	Traffic conditions are unacceptable for most drivers, intensity on the approaches exceeds the capacity of the intersection	$> 80$

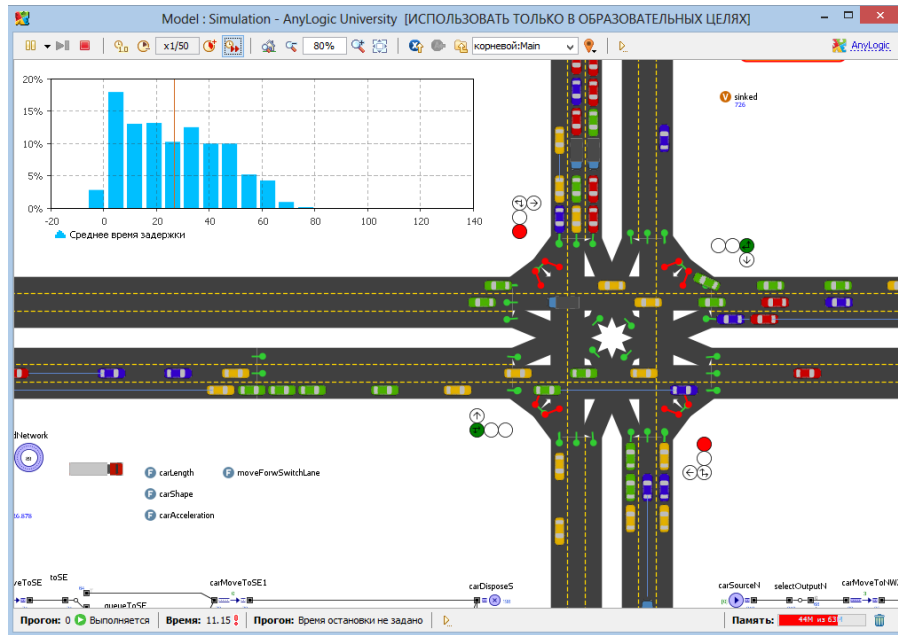
If in the process of measures ensuring the optimization of the operation of the regulated intersection, it was possible to achieve an improvement in the level of service by at least one level, then this result is significant and indicates the correctness of the choice of the method of traffic flow management.

## 2. Results

AnyLogic University was chosen as a platform for creating a simulation model (the version for educational institutions).

The developed simulation model (Figure 2) contains the following structural elements:

- quadrilateral intersection with adjacent roads on each side, each road has a central reservation dividing the road into two carriageways with three lanes in each direction;
- system of the model that generates agents - vehicles of two types: a car and a truck with a loading capacity from 2 to 6 tons;
- four units of vehicle logic (one for each direction), light-signaling element models - traffic lights;
- a state diagram simulating the switching logic of traffic lights based on double-ring phasing;
- a system dynamics module that simulates the operation of a local crossing controller, a block of model control parameters;
- a module for reading the parameters of tight regulation cycle from an external MSExcel file; a module for collecting statistics of agents parameters;
- histogram of the distribution of vehicles delay, showing also the average delay time of all vehicles throughout the experiment.



**Figure 2.** Model work in runtime.

The simulation model developed in AnyLogic can be used for decision support and covers all the stages of research process using simulation modeling.

A methodology of algorithm research was developed for conducting an experiment.

The input parameters of the model are:

1. Intensity of arrival of vehicles from the North ( $I_N$ ), East ( $I_E$ ), South ( $I_S$ ) and West ( $I_W$ ) approaches, veh./min.
2. The distribution of cars in the directions (left, straight, right) for each approach, %:
  - a) for the North approach:  $p_N^{\text{left}}$ ,  $p_N^{\text{straight}}$ ,  $p_N^{\text{right}}$ ;
  - b) for the East approach:  $p_E^{\text{left}}$ ,  $p_E^{\text{straight}}$ ,  $p_E^{\text{right}}$ ;
  - c) for the South approach:  $p_S^{\text{left}}$ ,  $p_S^{\text{straight}}$ ,  $p_S^{\text{right}}$ ;
  - d) for the West approach:  $p_W^{\text{left}}$ ,  $p_W^{\text{straight}}$ ,  $p_W^{\text{right}}$ .

### 3. Discussions

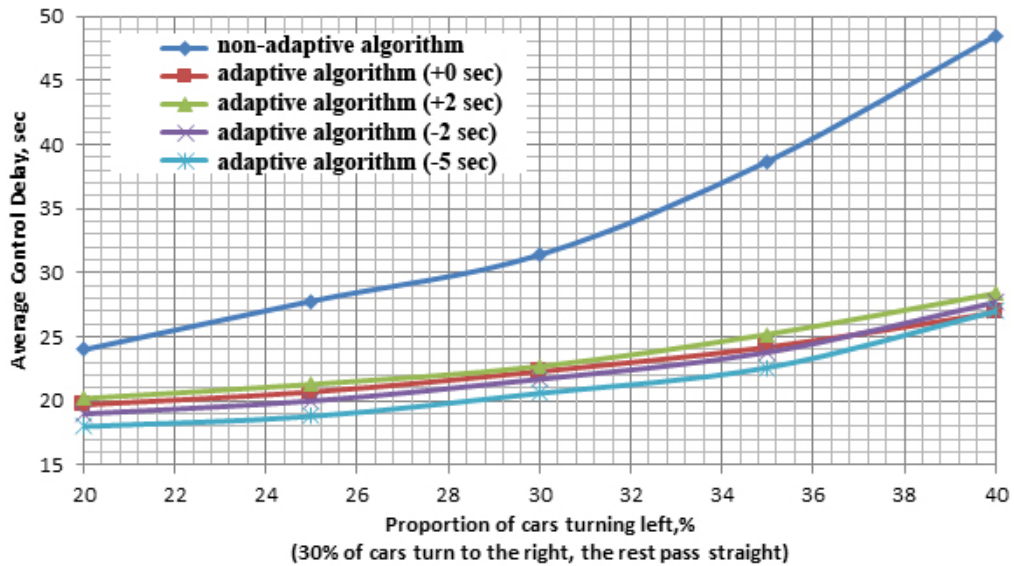
A total of 6 series of tests were conducted.

The first series of tests (experiments No. 1-5) was conducted in order to determine the dependence of the ACD at the intersection on the proportion of cars turning left. Input parameters and the results of the first series of tests are presented in Table 2. Graphic dependences are shown in Figure 3.

**Table 2.** Input parameters and results for a series of tests with varying proportion of vehicles turning left

Experiment number	1	2	3	4	5
$I_S$ , veh./h	900	900	900	900	900
$I_N$ , veh./h	900	900	900	900	900
$I_E$ , veh./h	900	900	900	900	900
$I_W$ , veh./h	900	900	900	900	900
$p_S^{\text{left}}$ , %	20	25	30	35	40
$p_S^{\text{straight}}$ , %	50	45	40	35	30
$p_S^{\text{right}}$ , %	30	30	30	30	30
$P_N^{\text{left}}$ , %	20	25	30	35	40

$P_N^{\text{straight}}$ , %	50	45	40	35	30
$P_N^{\text{right}}$ , %	30	30	30	30	30
$P_E^{\text{left}}$ , %	20	25	30	35	40
$P_E^{\text{straight}}$ , %	50	45	40	35	30
$P_E^{\text{right}}$ , %	30	30	30	30	30
$P_W^{\text{left}}$ , %	20	25	30	35	40
$P_W^{\text{straight}}$ , %	50	45	40	35	30
$P_W^{\text{right}}$ , %	30	30	30	30	30
Average Control Delay, sec					
non-adaptive algorithm	24(C)	27.8(C)	31.4(C)	38.7(D)	48.5(D)
adaptive algorithm (+0 sec)	19.7(B)	20.7(C)	22.3(C)	24.2(C)	26.9(C)
adaptive algorithm (+2 sec)	20.2(C)	21.3(C)	22.7(C)	25.2(C)	28.4(C)
adaptive algorithm (-2 sec)	19(B)	20(B)	21.7(C)	23.8(C)	27.7(C)
adaptive algorithm (-5 sec)	18(B)	18.8(B)	20.6(C)	22.6(C)	27(C)



**Figure 3.** Dependence of the Average Control Delay on the change in the number of cars turning left (experiments No. 1-5).

As it is seen from Figure 3 the use of adaptive control algorithm provides a significant reduction in the ACD, which rises with increasing proportion of vehicle turning left. Thus, with an increase in the intensity of vehicles moving to the left, the developed algorithm copes better with the organization of vehicle separation. In addition, the adjustment of the maximum duration of the green light signal showed that the ACD in this case can be reduced by 1-2 seconds while reducing the duration of the green light signal by 2-5 seconds.

The second series of tests (experiments No. 6-10) was conducted in order to determine the dependence of the ACD at the intersection on the proportion of cars turning right. The use of the adaptive control algorithm provides a significant reduction in the ACD, which in this case remains relatively constant when the proportion of vehicles turning right changes. However, with an increase in the intensity of cars moving to the right, the developed algorithm copes better with the organization of vehicles movement. The adjustment of the maximum duration of the green light signal showed that the ACD in this case can be reduced by 1-1.5 seconds with a decrease in the duration of the green light signal by 2-5 sec.

The third series of tests (experiments No. 11-15) was carried out with the aim of determining the

dependence of the ACD at the intersection on the proportion of vehicles passing straight.

The use of adaptive control algorithm provides a significant reduction in the ACD, which in this case is reduced by increasing the proportion of vehicles passing straight. In any case, with increasing intensity of cars moving straight, the developed algorithm copes better with the organization of vehicles movement.

The correction of the maximum duration of the green light signal showed that the ACD in this case can be reduced by 0.5–2 sec with a decrease in the duration of the green light signal by 2–5 sec.

The fourth series of tests (experiments No. 16 -20) was carried out to determine the dependence of the ACD at the intersection on the intensity of the movement of vehicles with an even loading of approaches.

The use of the adaptive control algorithm provides a significant reduction in the average delay, which in this case rises with an increase in traffic of vehicles, it indicates that the developed algorithm is better at the vehicles movement organization than non-adaptive algorithm.

The adjustment of the maximum duration of the green light signal showed that the ACD in this case can be reduced by 0.5–2.5 sec with a decrease in the duration of the green light signal by 2–5 seconds.

The fifth series of tests (experiments No. 21- 25) was carried out to determine the dependence of the ACD at the intersection on the intensity of the movement of vehicles with uneven loading of approaches (east and west approaches – 20% less).

The use of an adaptive control algorithm provides a significant reduction in the ACD; The effect is especially strong with a high arrival rate of vehicles, which indicates that the developed algorithm copes better with the organization of vehicles movement than non-adaptive algorithm.

Adjusting the maximum duration of the green light signal showed that the ACD in this case can be reduced by 1-2 seconds while reducing the duration of the green light signal by 2-5 seconds.

The sixth series of tests (experiments No. 26-30) was carried out to determine the dependence of the ACD at the intersection on the intensity of the movement of vehicles with uneven loading of approaches (east and west approaches – 40% less).

The use of an adaptive control algorithm provides a significant reduction in the ACD; with the increase in the intensity of the arrival of vehicles, the effect of reducing the ACD slightly increases, which indicates that the developed algorithm copes better with the organization of moving vehicles than non-adaptive algorithm.

The adjustment of the maximum duration of the green light signal showed that the ACD in this case can be reduced by 1-1.5 sec with the decrease in the duration of the green light signal by 2-5 sec.

#### **4. Conclusion**

The research resulted in the following conclusions:

1. The application of the developed algorithm for the management of traffic flows based on adaptive control methods helps to reduce the average delay at intersections in all considered diapasons of input parameters and increases the level of service (LOS), which allows speaking about the correctness of the choice of adaptive control methods as the basis of the algorithm. The operation of this algorithm is more stable compared to the operation of algorithms based on the use of pure local adaptive traffic control methods, which is confirmed by experimental data obtained using a simulation model in the course of changing model parameters in a wide range of values.

2. Reducing the average delay varies over a wide range depending on the incoming parameters of traffic flows, which is evidence of the need to further develop the algorithm in order to identify factors complicating the operation of the adaptive control algorithm, as well as ways to reduce the influence of these factors on the operation of the algorithm.

3. With the increase in the share of vehicles moving straight, the operation of the adaptive control algorithm is most closely approximated to the operation of non-adaptive algorithm.

4. In general it can be stated that the choice of method for determining the maximum duration of the green light signal for the adaptive algorithm in the first approximation is valid.

5. With the increase in the intensity of vehicle traffic, the reduction in the average delay in comparison with non-adaptive algorithm increases, which necessitates the use of adaptive control techniques traffic in urban district, regional and federal levels, and in particular on those streets where during peak traffic intensities are formed multiple congestions.

The analysis shows that measures to reorganize road traffic in large cities, based on the introduction of ATCS, contribute to the improvement of urban logistics by reducing the number of traffic congestion on the roads, reducing harmful pollutions from vehicle exhaust gases and reducing the costs connected with the vehicle operation.

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